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Rescue Robot League Competition
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www.robocup-us.org

RoboCupRescue - Robot League Team Remote Operated and Controlled Hexapod (ROACH) Robot, USA

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Abstract. This paper outlines the functionality and practicality of the Remote Operated and Controlled Hexapod robot, (ROACH). The ROACH platform has been designed by Colorado State University in conjunction with S.A. Robotics, to provide a platform for robotics research in unstructured environments. Aspects discussed in this paper are operation setup, communications, control architecture, graphical user interface, sensors, and real world application of ROACH.

Introduction

The Remotely Operated and Controlled Hexapod, (ROACH), robot was created specifically for human detection in urban environments. Because the ROACH robot was tailored to a USAR environment, the design team anticipates a high degree of mobility. The ROACH robot, see Figure 1, is a compliant six legged design that provides significant advantages in mobility over wheeled and tracked designs. A robotic arm equipped with cameras and other sensors is also incorporated allowing for better sensor positioning. The operating system consists of predefined walking gaits, including stair climbing, while also allowing for optional manual control of individual legs. ROACH is managed remotely by a single operator via wireless radio communications and the use of a graphical user interface. The ROACH robot transmits live audio and video of the disaster site, as well as information about locations of objects with respect to the robot's position to the interface on the laptop. The operator interface provides the user with appropriate sensor data assisting with the location and assessment of victims. Sensor data is also compiled by the user interface to generate a map that may be used by rescue workers to assist in location of victims. With its portability, mobility, victim identification, and mapping abilities, ROACH is capable of completing rescue and reconnaissance tasks within an USAR environment.

Figure 1. Photo of ROACH

1. Team Members and Their Contributions

• Team Leader:	Chris Cappello
• Operator:	TBD
• Structures:	Chad Olsen
	Ken deAlmeida
• Dynamics:	Travis Cochran
• Real Time Systems:	Justin Vallely
	Kristin DeLalla
	Mike Auen
• Electrical:	Bryce Eldrige
	JT Barth
	Matt Newbill
	Joven Deharerra
• Project Funding:	SA Robotics

- Project Advisors: Mr. Sam Johnson, CTO, S.A. Robotics
  Prof. Wade Troxell, CSU
  Prof. Anthony Maciejewski, CSU
  Mr. Carl Kaiser, CSU

2. Operator Station Set-up and Break-Down (10 minutes)

2.1 Packaging

The ROACH robot is designed for rapid field deployment. The robot, control station, and all systems required for operation will fit securely in a suitcase weighing less than fifty pounds. While in the suitcase the ROACH robot will be fully assembled and ready for operation. Prior to packing, the ROACH robot will be thoroughly inspected and all necessary maintenance performed according to the checklist in Appendix A, so that upon deployment the ROACH robot can be set-up in less than ten minutes .

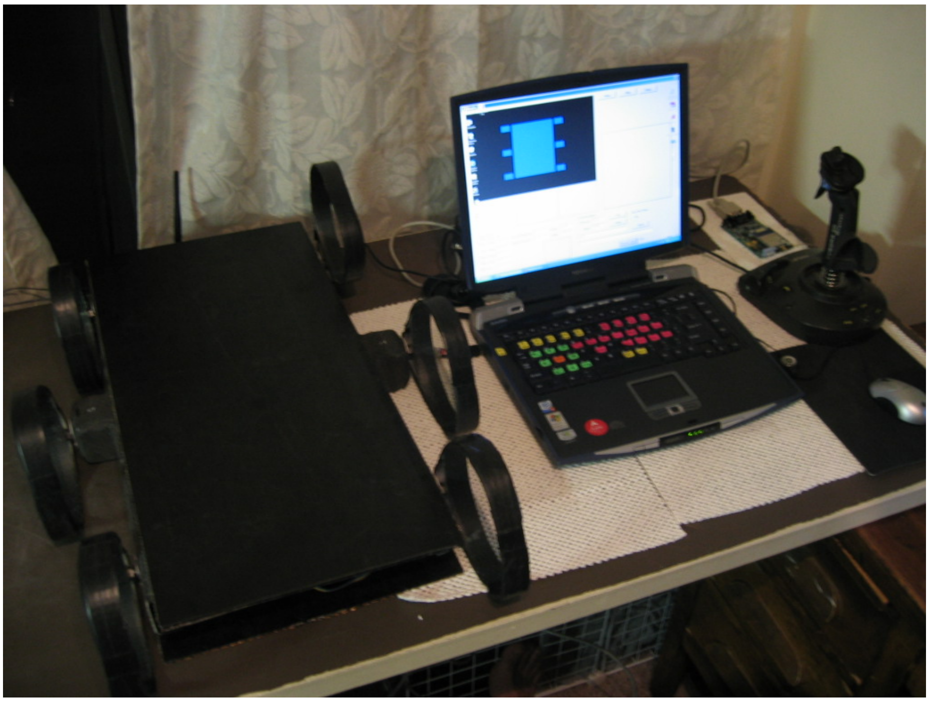

Figure 2. Station set up ready for deployment

2.2 Set Up

The packaging of the ROACH robot allows for short setup times, as most system components are preassembled. The majority of time in setup comes from starting the laptop. A picture of the ROACH robot ready for deployment is shown in Figure 2. To ensure the ROACH robot is properly setup, a check list will be provided to the operator. During setup, the checklist shown in Figure 3 will be performed.

Start-up checklist

- ☐ Laptop setup
  - o Connect power cord to laptop and plug in
  - o Connect wireless transmitter/receiver to laptop
  - o Connect joystick to laptop
  - o Connect printer to laptop
  - o Boot up laptop
- ☐ Wireless communication
  - o Wireless uplink established
  - o Signal strength is strong
  - o All cameras broadcasting
  - o Microphone broadcasting
  - o Robot movement corresponds to joystick movement
- ☐ Check Battery State

Figure 3. Start-up Checklist

2.3 Break-Down

During breakdown the checklist shown in Figure 4 will be performed.

Break-down checklist

- ☐ Robot
  - o Make sure ROACH is lying on the ground, not standing
  - o Turn off power to all boards
  - o Place ROACH into the suitcase in the correct position
- ☐ Laptop
  - o Close all programs
  - o Turn power off
  - o Disconnect all external hardware
- ☐ Pack-up
  - o Insert laptop into suitcase
  - o Place all wireless hardware into correct positions in suitcase around ROACH
  - o Pack up all power cables
  - o Pack up joystick
  - o Pack up printer

Figure 4. Break-down Checklist

3. Communications

Communication between the ROACH robot and the operator is wireless. The ROACH robot incorporates a dual frequency communication system. One frequency, hereafter referred to as the command and control (C&C) frequency, is used for operator control and most sensor data. The second frequency is used for audio and visual data. The C&C channel is implemented on a MaxStream 9XStream 900MHz band transmitter. The audio and video transmitter is an AVX-434-Mini-A 433.92MHz transmitter, as shown in Figure 5.

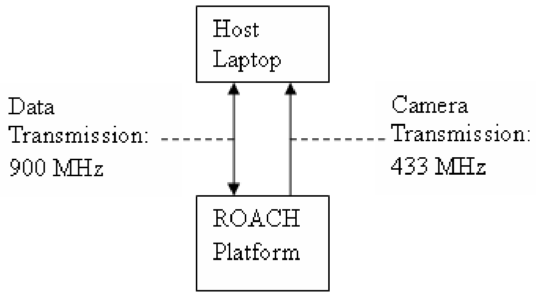

Figure 5. ROACH Communications Flow Chart

All members of the ROACH team are FCC Amateur HAM Radio Operation Licensed for use of the 433.92MHz bandwidth. The C&C transmitter interfaces to the control board via RS232, while the video transmitter provides a direct data path between the onboard video cameras and the operator interface. The C&C transmitter/Receiver is a variable power unit capable of transmission from 1mW to 1W depending on power required to provide an adequate signal. The video transmitter consumes 100mW of power. In the event of a communications loss, the ROACH robot will cease movement and attempt to reacquire the signal. The radio frequencies and channels used by the ROACH robot are shown in Table 1.

Table 1. ROACH Communication Channels

Rescue Robot League		
ROACH (USA)		
Frequency	**Channel/Band**	**Power**
900 MHz	902-928 MHz	1mW-1000mW
400 MHz	433.92 MHz Television Channel 59	100 mW

4. Control Method and Human-Robot Interface

Onboard control of the ROACH robot is achieved using a network of micro-controllers, including a master processor which interfaces with the operator, a processor for motor coordination, and six servo motor controllers. See Figures 6 and 7.

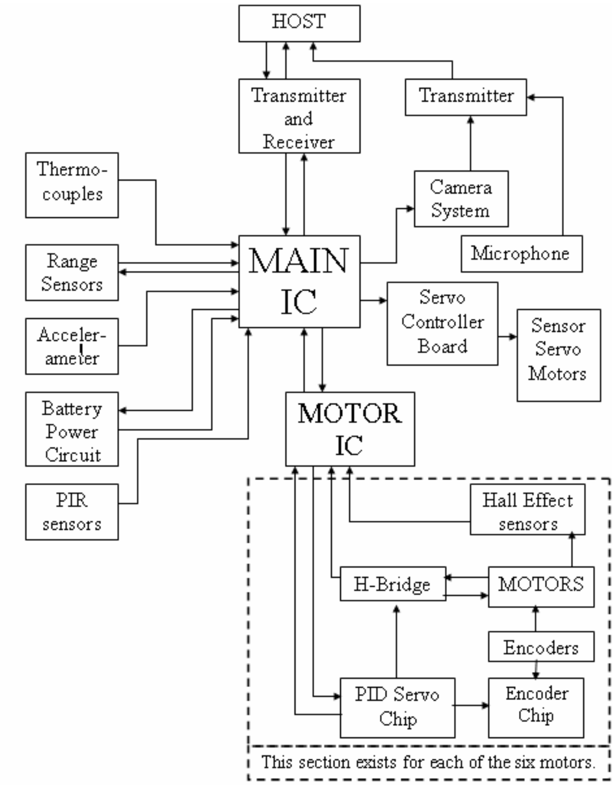

Figure 6. ROACH Control Flow Chart

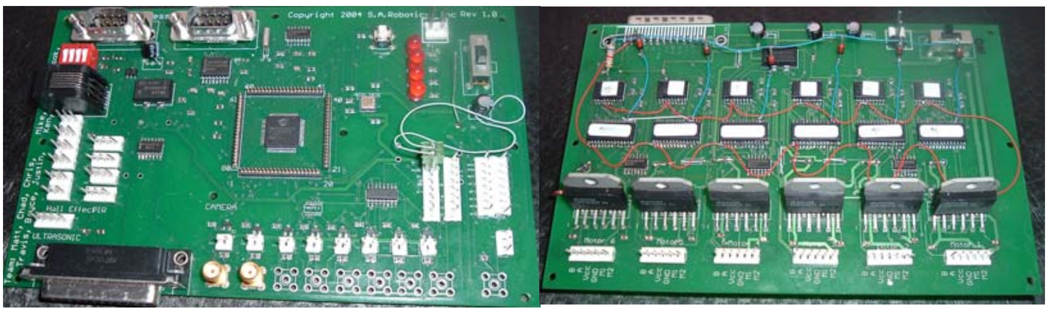

Figure 7. ROACH Circuit Boards

4.1 On Board Control

Motor control is achieved through position encoders as well as hall effect sensors for absolute position referencing. This system offers an onboard position, velocity, acceleration, current, and absolute position control capabilities for each individual motor. This data is used to generate a series of preprogrammed walking gaits. The master micro-controller also switches between cameras, provides arm control, and passes sensor data to the wireless transmitter. The motor coordination micro-controller is used to implement preprogrammed walking gaits with single commands, relayed from the operator via the master micro-controller.

As a further precaution, situations of entanglement in obstacles such as netting, wires, etc. will cause the control system to automatically pause operation in order to prevent damage to ROACH or to the surrounding environment. Recovery gaits can then be implemented by the operator, such as reverse operation of any pre-defined gait, or operator defined movement to free ROACH from the surroundings.

4.2 Graphical User Interface

Human/Robot interaction is through a graphical user interface (GUI) which concurrently displays sensor data and telemetry on a laptop screen. The intent of the GUI is to reduce operator workload as much as possible by providing the user with an intuitive drive interface as well as easily accessed and well organized sensor data. The ROACH robot uses a combination of keyboard and joystick control. The joystick provides primary motion control while keyboard commands are used to engage obstacles such as stairs. The commands to the robot consist of a speed factor and the directions: forward and turn, reverse and turn, or turn in place, see Figure 8. This architecture simplifies onboard processing and is sufficient for task achievement.

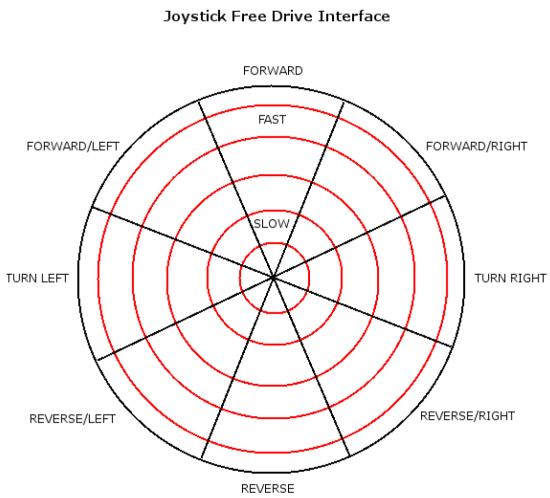

Figure 8. Joystick Free Drive Interface

The sensor data from ROACH is displayed on a single GUI in multiple windows. The main display window of the GUI has three display options, the video transmission, generated map, and on board status information. Operator chooses between windows by clicking buttons within the main GUI window. The video feed will be the background for the other displayed information in this window if another view is chosen. See figure 9.

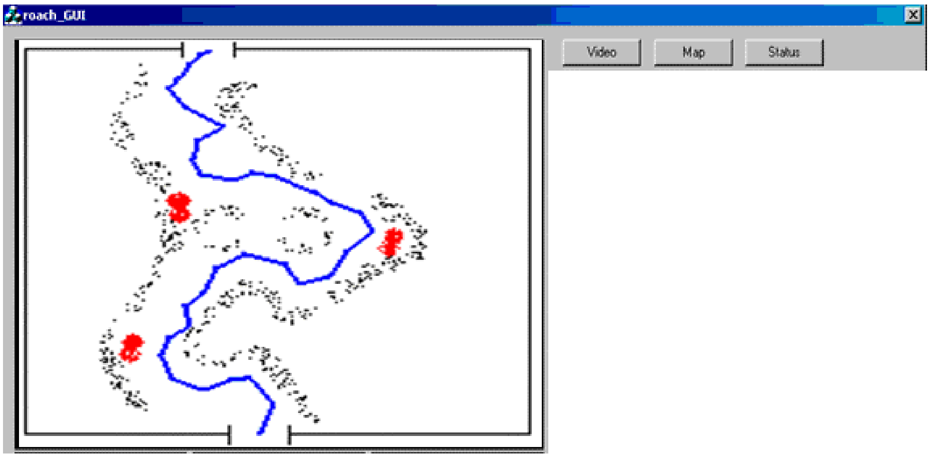

Figure 9. Main GUI window with selection buttons

Another window will display PIR alerts, motor current status, and current camera selection. Color and sound will alert the user to the pertinent information in this window. See Figure 10.

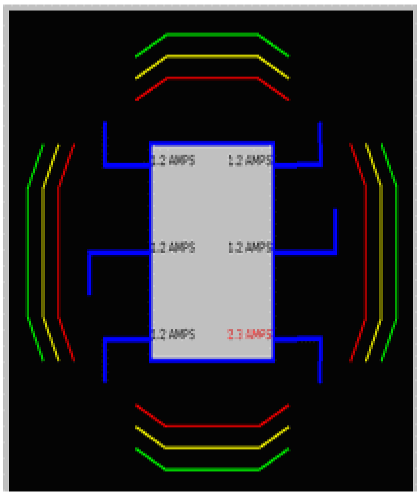

Figure 10. ROACH overall status window

A third window will display a graphical representation of obstacles around ROACH. See Figure 11. Figure 12 shows an overall preliminary screenshot of the user interface with the map selected in the main window.

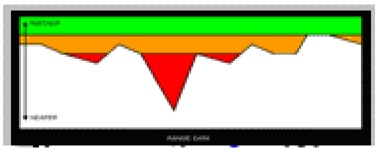

Figure 11. Graphical representation of obstacles

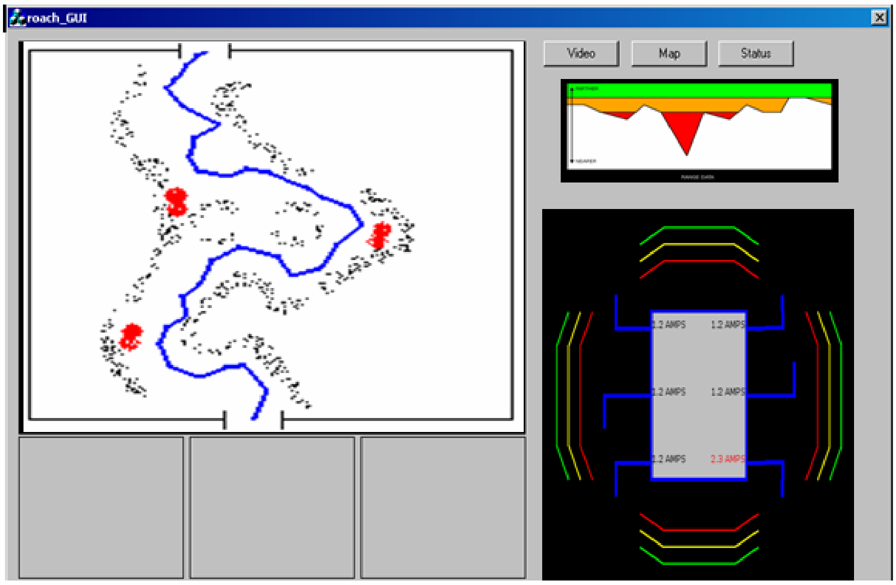

Figure 12. User Interface Display

5. Map generation/printing

The mapping program combines data received from the ultrasonic sensors and the accelerometer, to create a map of the robots path in relation to the surroundings. Data from the victim detection sensors is interpreted by the operator and will be manually added to the map to clearly locate a victim.

Acceleration data from a dual-axis accelerometer is integrated to determine the path of the ROACH robot. See Figure 13 for a simulated map of accelerometer data. Drift in the accelerometer data is acknowledged to be a problem and solution methods are under consideration.

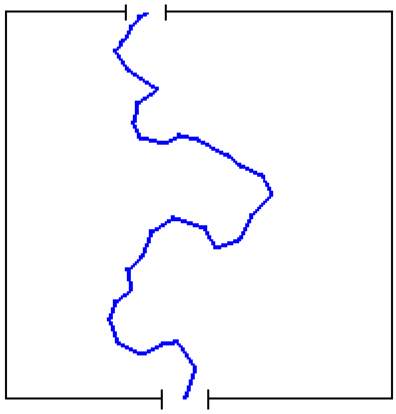

Figure 13. Map of accelerometer data.

Data from the laser range sensors will be used to locate obstacles in the environment using the accelerometer derived position as a reference. See figure 14 for a simulated map of this data. Range data will then be overlaid with the accelerometer to display the locations of obstacles relative to ROACH. See Figure 14 for composite map from accelerometer and ultrasonic range data.

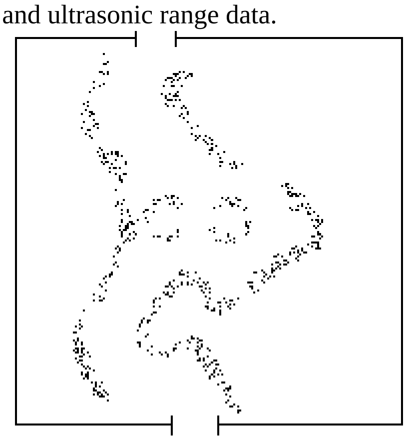

Figure 14. Map of Ultra-sonic Range Data

A composite map of the above figures overlaid on top of each other along with the operator noted points, gives a printable map that can be handed to emergency personnel. See figure 16.

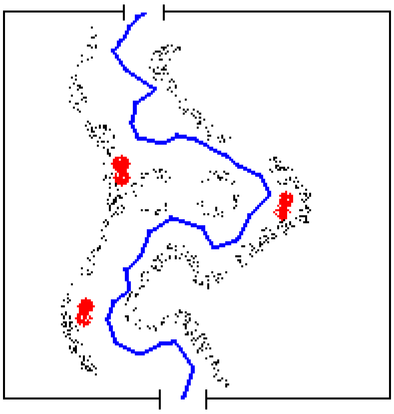

Figure 15. Printable Composite Map

The blue line in figure 15 is the accelerometer path; the black dots are the ultrasonic range data with respect to the accelerometer data. The red spots are operator defined points from the PIR sensors indicating heat sources.

6. Sensors for Navigation and Localization

The ROACH robot uses laser range sensors (LADAR), and ultrasonic range sensors for obstacle detection and mapping; an accelerometer for position determination; and video cameras for operator orientation. The LADAR system will be mounted on the top of the ROACH robot while the ultrasonic range sensors will be placed around the perimeter of the chassis to provide 360 degree obstacle detection. These two systems will function in conjunction with each other to detect and confirm the presence of obstacles, the data collected will be assimilated by the GUI mapping program. The accelerometer will be used to determine and track the path the ROACH robot traverses through the environment. Cameras placed around the perimeter of ROACH give the operator continuous stream of detailed environmental views. Higher resolution cameras will be located at the front of the ROACH robot and on the tip of a mobile environmental observation arm on the top of the robot, with lower resolution cameras located on the sides and back. See Figure 16.

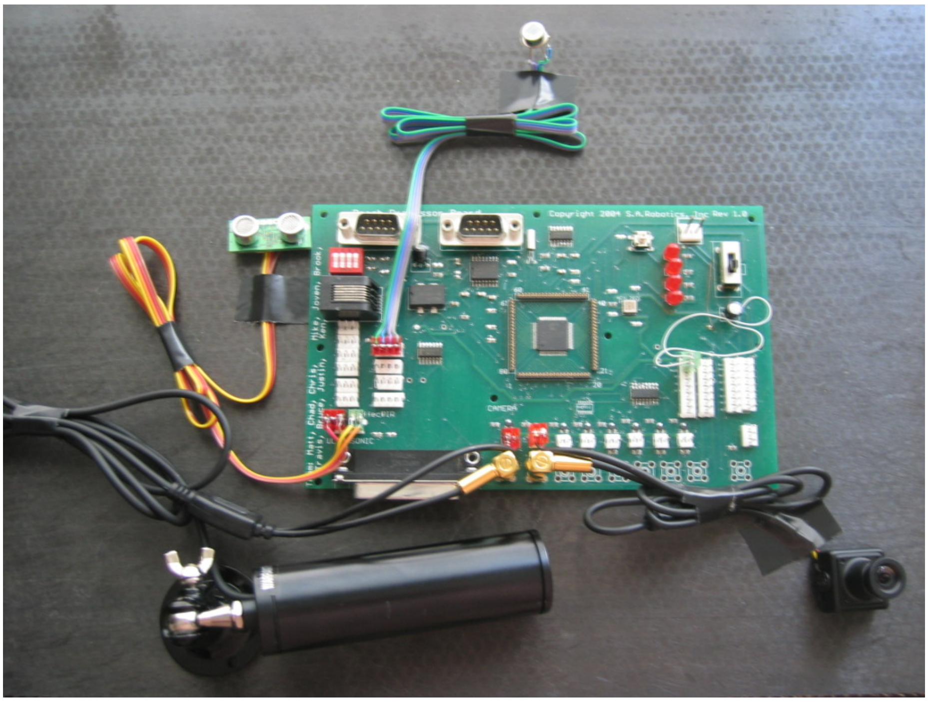

Figure 16. Main Control Board with two Cameras, Ultrasonic Ranger, and PIR Sensors Hooked up to Appropriate Pins

7. Sensors for Victim Identification

In addition to using video cameras as discussed above, an infrared camera, pyroelectric infrared (PIR) sensors, and a microphone will be used in victim identification. The video cameras provide feedback showing victim movement and form, as well as being useful in viewing victim identification tags. The infrared camera, mounted on the front of the ROACH robot, provides information on heat sources, which can then be inspected with a video camera for other victim characteristics. The PIR sensors are located around the perimeter of the ROACH robot to provide 360 degree temperature detection. They detect temperature variation within the environment and send an alert to the GUI, which will provide the user with information about the direction in which the heat source was detected. Finally, the microphone provides audio feedback from the environment to help in the detection of victims emitting sounds.

8. Robot Locomotion

8.1.1 Leg Design

ROACH is a walking robot with six one degree of freedom legs. The single degree of freedom per leg allows ROACH to retain many of the advantages of wheeled motion while gaining much of the mobility associated with legged motion. Using a single actuator for each leg also reduces the weight and complexity of the robot. See Figure 17.

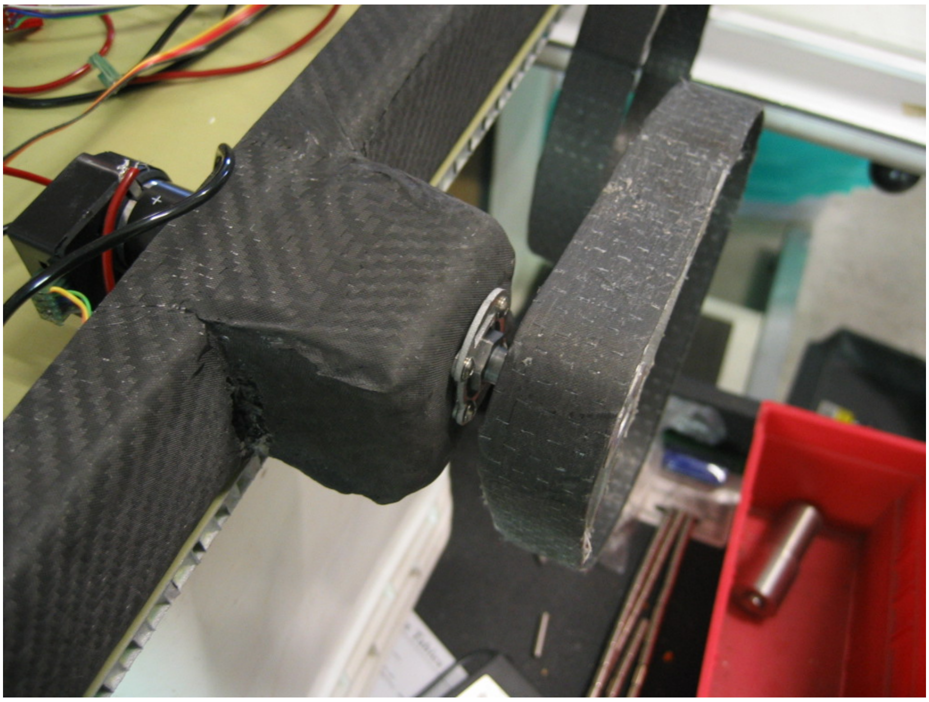

Figure 17. Leg-motor system

8.1.2 Partial Wheel Design

The legs of ROACH are a synthesis of a wheel design and a cam lifter. The legs are made of a unidirectional carbon fiber strip approximately .044 inches thick by 1 inch wide bonded to an aluminum insert. See Figure 19. Because the legs have a fixed hip at the motor shaft, smooth contact with the ground is a concern. It is undesirable for the robot to have to lift the center of gravity while walking, or for it to compress the leg in order to achieve a reasonable contact patch with the ground. As a result a mathematical cam profile was used to increase stability and minimize energy consumption. This design allows the legs to act much like a wheel on flat terrain, and also adds stability to the robot as the point of contact on the ground is always directly below the motor. See Figure 18 The lower area is left open to allow for compliance in the leg.

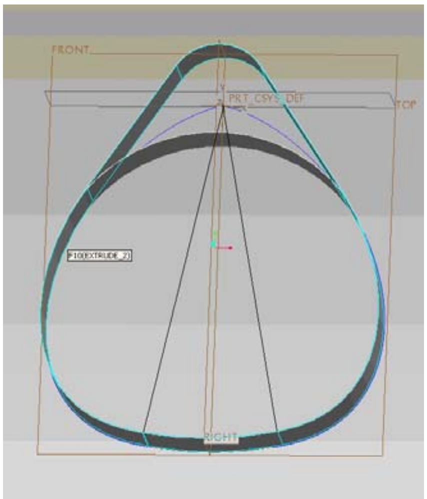

Figure 18. CAD Design of Leg

Figure 19. Actual leg design

8.2 Pre-Programmed Gaits

Ten gaits have been preprogrammed and are stored on board the motor micro-controller, allowing the operator to be freed from individual leg control.

8.2.1 Walking

Six legs is the minimum number of legs necessary for statically stable walking. Under flat and lightly varied terrain an insect inspired tripod gait is used for locomotion, as this allows rapid movement. Legs are grouped into two sets, and each set has three legs that move in unison. Legs are numbered one through six as shown in Figure 20, under the tripod gait legs 1,3,5 are grouped and 2,4,6 are grouped. Figure 21 demonstrates the progression of the tripod gait.

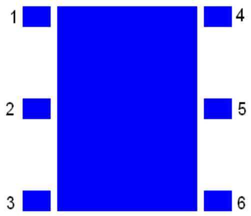

Figure 20. Leg Location on ROACH robot

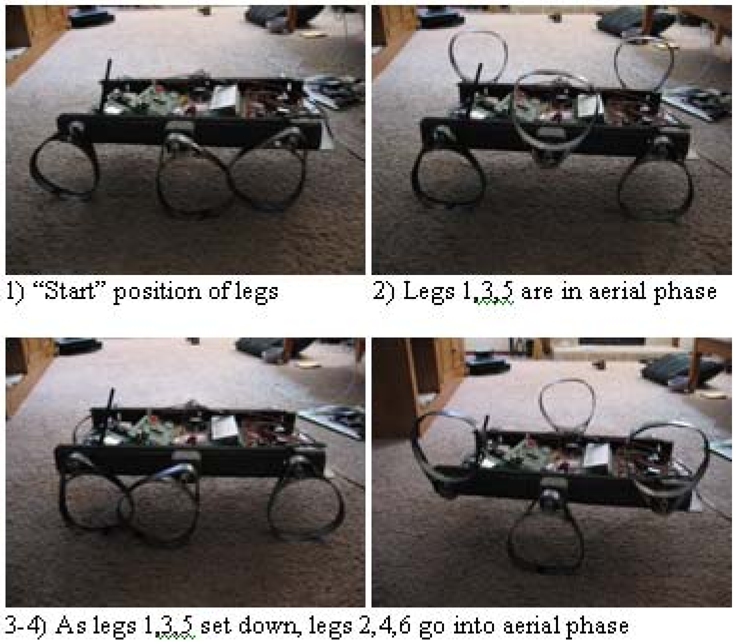

Figure 21. Tripod Gait

8.2.2 Obstacle Navigation

In challenging situations, such as moving over pipes or stairs as shown in Figure 23, a sequential gait will be used in which pairs of legs on each side of the ROACH robot. Leg numbers: (1,4), (2,5) (3,6) will be paired. The ROACH robot will use the first set to pull itself up on any obstacle, and the middle and rear set will push the robot up and over the obstacle. In extreme circumstances the legs can be independently controlled by the operator allowing for flexibility in unanticipated environments. This flexibility also allows for remote disentanglement of the ROACH robots legs should it become necessary.

9. Other Mechanisms

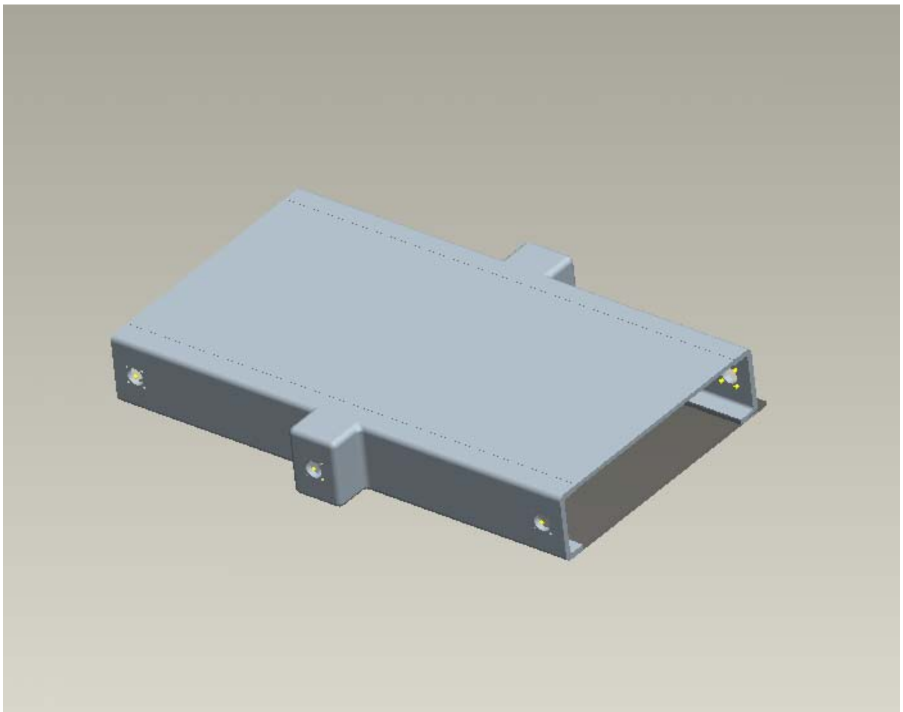

Figure 22. CAD Model of Chassis

The chassis consists of two parallel carbon fiber C-channels connected by honeycomb plates across the flanges, see Figure 22. An offset at the center of each channel keeps the center leg from interfering with the outer legs. The top plate of the chassis provides a mounting point for the arm and laser rangers.

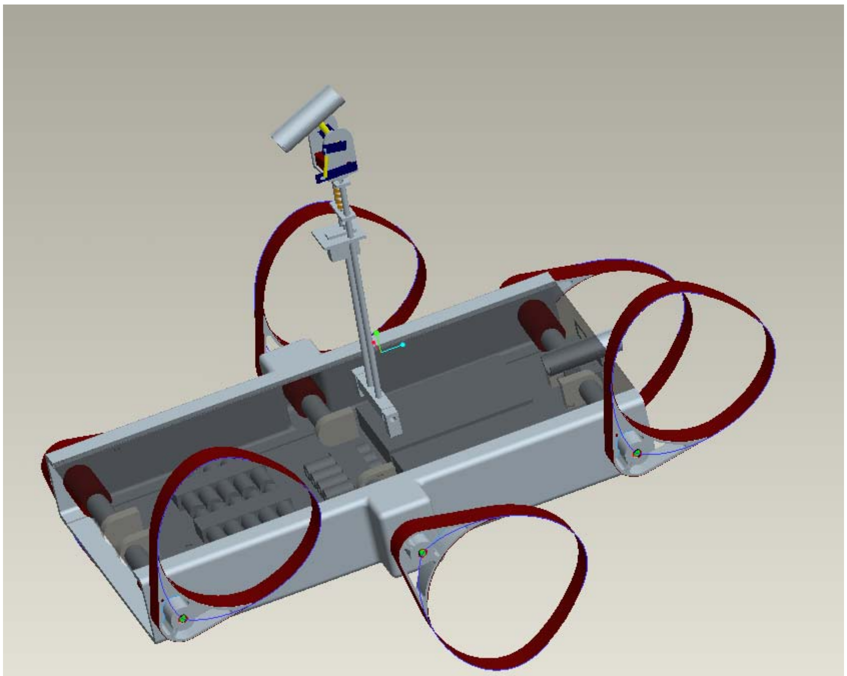

Figure 23. Environmental Observation Arm on ROACH

The robotic arm that holds the infrared camera, shown in Figure 23, will have a wide range of motion and viewing angles. The arm is a three degree of freedom system utilizing three small servo motors for actuation. The light weight design of this assembly allows for arm movement while ROACH is moving in motion. The environmental observation arm can also be folded flat on the top side of the chassis for ease of transport and for moving through small spaces.

10. Team Training for Operation (Human Factors)

Minimal training is required to familiarize an operator with the ROACH robot. The robot can be handled by one person during set-up, and only four cable connections are required to prepare ROACH for deployment. The GUI provides a simple, intuitive interface that allows the robot to be operated with little or no training. Robot locomotion can controlled through the joystick, while the sensor data is automatically displayed on the GUI in a logical, self-explanatory manner. The operator's performance will improve with training as the operator becomes more familiar with keyboard commands, robot performance, and the assimilation of sensor data. A training session in victim identification techniques will improve the accuracy of the operator in victim detection by informing the operator of patterns and cues that identify human life. A test course will be built to familiarize Colorado State University operators with the functions and performance of ROACH in a USAR environment.

11. Possibility of Practical Application to a Real Disaster

The ROACH robot is designed to allow easy migration to an environmental hardened package. It was designed for mobility in a wide range of environments including obstacles and unstable terrain. The ROACH robot is small, light, and portable, with the ability to be backpacked in to a disaster site. Its fast set-up would allow for rapid deployment in a real-world situation, and its small size would allow it to negotiate narrow paths through rubble. The chassis of the ROACH robot can be upgraded to be watertight and heat-resistant, to improve its performance in extreme rescue environments. Finally, the entire platform can be built for a relatively low cost. The materials for the robot and laptop can be purchased for approximately $20,000: a fraction of the cost of comparable robots currently on the market.

12. System Cost

TOTAL SYSTEM COST (per robot): Approximately $20,000.00

KEY PART NAME: Li/Poly Batteries
PART NUMBER: PQ2S-4400N
MANUFACTURER: Polyquest
COST: $541.00
WEBSITE: www.robotcombat.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: Ultrasonic Ranger
PART NUMBER: R241-SRF10
MANUFACTURER: Acroname
COST: $57.00
WEBSITE: www.acroname.com
DESCRIPTION/TIPS: Used an array of three around the perimeter of the robot to acquire mapping in the entire 2-D space.

KEY PART NAME: Ultrasonic Ranger
PART NUMBER: R241-SRF8
MANUFACTURER: Acroname
COST: $57.00
WEBSITE: www.acroname.com
DESCRIPTION/TIPS: Incorporated a more precise ranger with heat sensory capabilities for mapping and navigation from the front of the robot.

KEY PART NAME: High res. Camera
PART NUMBER: PC209IR
MANUFACTURER: Super Circuits
COST: $149.95
WEBSITE: www.supercircuits.com
DESCRIPTION/TIPS: Placed high resolution camera on an actuated arm for greater visibility by the user.

KEY PART NAME: IR heat sensing Camera
PART NUMBER:
MANUFACTURER:
COST: $10,000.00
WEBSITE: www.robotcombat.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: Laser range finder
PART NUMBER:
MANUFACTURER:
COST: $,2500.00
WEBSITE:
DESCRIPTION/TIPS: Use one on each side, optimizing the 270 degree range for double coverage in-front and back of ROACH.

KEY PART NAME: PIC Microprocessor
PART NUMBER: PIC18F6520
MANUFACTURER: Microchip
COST: $11.00
WEBSITE: www.microchip.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: Wireless
PART NUMBER: 9XTend 900 MHz OEM RF Module
MANUFACTURER: MaxStream
COST: $500.00
WEBSITE: www.maxstream.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: H-Bridges
PART NUMBER: LMD18201
MANUFACTURER: National Semiconductor
COST: $8.00
WEBSITE: www.nationalsemiconductor.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: Accelerometer

PART NUMBER: ADXL202E*
MANUFACTURER:
COST: $30.00
WEBSITE: www.analog.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: Astroflight 109 Li-Poly Charger
PART NUMBER:
MANUFACTURER: Apogee
COST: $130.00
WEBSITE: www.robotcombat.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: Motors, Gear head, Encoder
PART NUMBER: RE 25 20W, Planetary Gear head GP 32C, Digital Encoder HEDS 5540
MANUFACTURER: Maxon Motor
COST: $450.00
WEBSITE: www.maxonmotor.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: Servo Module Controller
PART NUMBER: SD21
MANUFACTURER: Daventech
COST: $50.00
WEBSITE: www.acroname.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: PIC Servo Chip
PART NUMBER: KAE-TOV4-SOS
MANUFACTURER: J.R. Kerr
COST: $35.00
WEBSITE: www.jrkerr.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: RS232 Drivers/Receivers
PART NUMBER: MAX232
MANUFACTURER: Maxim
COST: $10.00
WEBSITE: www.maxim-ic.com
DESCRIPTION/TIPS: Read all safety and warranty information before using.

KEY PART NAME: 1” thick 6061-T6 Al Plate
PART NUMBER:
MANUFACTURER:
COST: $200.00

WEBSITE:	
DESCRIPTION/TIPS:	Read all safety and warranty information before using.

KEY PART NAME:	Couplers for legs
PART NUMBER:	A 7Z39M0610
MANUFACTURER:	Stock Drive Products
COST:	$28.00
WEBSITE:	www.sdp-si.com
DESCRIPTION/TIPS:	Read all safety and warranty information before using.

KEY PART NAME:	Carbon fiber for legs and chassis and epoxy and hardener
PART NUMBER:	
MANUFACTURER:	
COST:	$300.00
WEBSITE:	
DESCRIPTION/TIPS:	Read all safety and warranty information before using.

KEY PART NAME:	Pyroelectric Sensor
PART NUMBER:	R3-PYRO1
MANUFACTURER:	Acroname
COST:	$60.00
WEBSITE:	www.acroname.com
DESCRIPTION/TIPS:	Read all safety and warranty information before using.

APPENDIX A: Robot Inspection Checklist

- Robot inspection
  - Inspect circuit boards
    - No components broken off
    - Heat sink securely fastened to h-bridges
    - Boards not cracked
    - All jumper wires still intact
  - Inspect cables
    - Power to all circuit boards (correct polarity)
    - Motor connections to motor control board
    - Encoder connections
    - Hall effect sensors (both ends of cable)
    - Cameras (power and coax)
    - Wireless (RS-232 ports)
    - Range Finders
  - Power source
  - Physical wellbeing
    - Legs
      - Not cracked
      - Inserts secured in carbon fiber
      - Coupler secured to motor shaft
    - Chassis
      - C-channels not cracked
      - Body plates not cracked
      - Body plates securely fastened to c-channels
    - Motors
      - Drive shafts spin freely
      - Motors securely attached to chassis
      - Motor heat sinks attached properly
      - All secondary servo-motors connected properly
      - All secondary servo-motor mechanisms move freely
    - Sensors
      - Cameras attached securely
      - Camera lenses uncovered and unbroken
      - Range finders connected properly
      - PIR sensors connected properly
      - CO_2 sensors connected properly
      - Microphone connected properly